

EVALUATION OF GRANULAR ACTIVATED CARBON SAND BASED FIXED BED TREATMENT OF NATURAL WATERS FOR TRACE METAL REMOVAL

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Laboratory evaluation and system operation are assessed for the feasibility of use of granular activated carbon (GAC) in GAC-sand beds for trace metal removal from natural waters. Carbons of different particle size, toughness and specific surface area are used in two fixed bed PVC columns (150 x 15 cm) operating in a 2-stage mode for 2 x 30 mins. contact time. Operation criteria are evaluated in terms of bed space velocity, flow rate, function mode and regeneration of spent carbon. The operation aspects are based on adsorption isotherm studies at the pH of working samples. The technique is applied to treat natural water samples containing normal and excessive amounts of Fe, Cr, Zn, Cu, Pb, Cd and Hg. With an activated carbon having specific surface of 1220 m²/g the trace metal removal ranges between 41.6 - 54.6% at ambient temperature and for given chemical characteristics of waters. The technique affords a convenient and direct procedure for lab-scale trace metal removal from natural waters for specific applications and has the potential of application on any desired scale.

Key words: Active carbon fixed bed filtration, Trace metal removal by granular carbon,

Introduction

In recent years health hazards associated with natural waters contaminated with trace metals have been given due recognition [1]. Consequently, various water treatment techniques have appeared for effective contaminant removal. The application of granular activated carbon (GAC) for the removal of particulate, colloidal and organic matter, together with heavy toxic trace metals, from contaminated natural waters is time-honoured and well known [2,3]. The deep-bed filtration technique for the purification of domestic and industrial wastes employing carbon-sand beds affords a safe and direct method of water treatment [4,5]. New trends in the field include designing and developing single- and multi-stage carbon loaded fixed bed systems for trace metal removal from such waters [6,7]. Other important aspects of water treatment include micro and ultra-filtration for separating micro-organisms [8,9], ceramic filtration for removing non-metallic inclusions [10] and membrane filtration for desalination [11]. Rapid gravity filtration beds have been developed for removing organo-mercurials either from waste waters or from pyrometallurgical processing of minerals [13,14]. Activated carbon thus finds extensive use in the purification of contaminated waters.

In line with the above developments an attempt was made in the present investigation to evaluate the usefulness of granular activated carbon for reducing toxic trace metal levels in natural waters containing normal and excessive amounts of the metals. The objective of the study was to define operational and development aspects of rather inexpensive granular activated carbon-sand water filtration columns working in series

for trace metal removal from public utility waters, as compared with expensive and more complicated ion-exchange technique used in laboratories for limited application. The quantitative aspects of the investigation included evaluation of adsorption isotherms, contact time and breakthrough volume. Five activated carbons of different particle sizes were tested for their effectiveness for trace metal removal from natural waters. The trace metal adsorption study was conducted for two natural water samples at constant pH (= 7.2 and 7.6) and temperature (= 18°) using gravity based flow with contact times extending from 60 to 90 mins. The technique developed was successfully applied for reducing the trace metal burden in natural waters samples from two locations known to have high metal levels. The metals included in the study were iron, chromium, zinc, copper, lead, cadmium and mercury.

Materials and Methods

Aldrich granular carbon, ranging in effective size from 0.50 to 1.00 mm, was ground up to give various particle sizes listed in Table 1. The sand used was first washed with 5% nitric acid, then thoroughly with water, followed by a final wash with distilled water, it was then dried before packing in the PVC column. A 3 cm layer of carbon, separated by a sand slice of about 12 cm width, provided an adequate gravity based packing repeated throughout the column. Each column required about 2.5 kg of carbon, filling approx. 20 % of the available internal volume of the column. The trace metal adsorption isotherm (Fig. 1) was obtained by equilibrating a fixed volume (= 1L) of a given water sample with a series of known amounts of carbon ranging between 0.1 - 5.0 g. The

amount of a trace metal removed per unit mass of the adsorbent (x/m) was used to compute volume throughput and effective contact time (Fig. 2). Two beds in series were used in this study, as described in (Fig. 3). Trace metal removal was

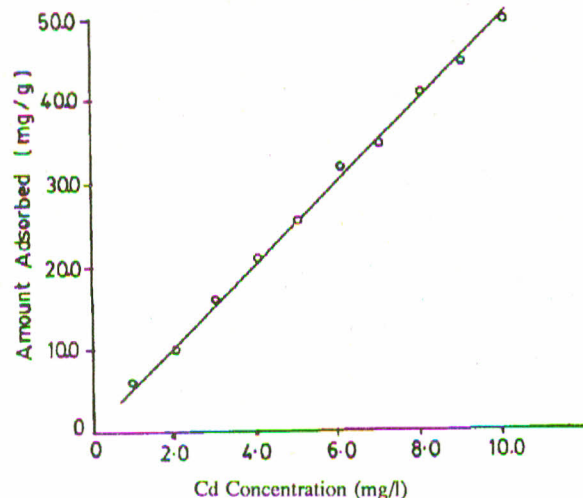


Fig. 1. Carbon-water (Cd) system isotherm on C-4 at pH 7.2.

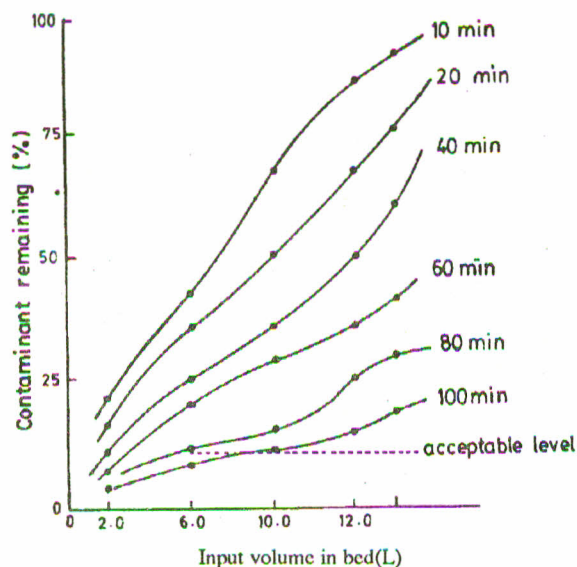


Fig. 2. Adsorption pattern in real bed using C-3.

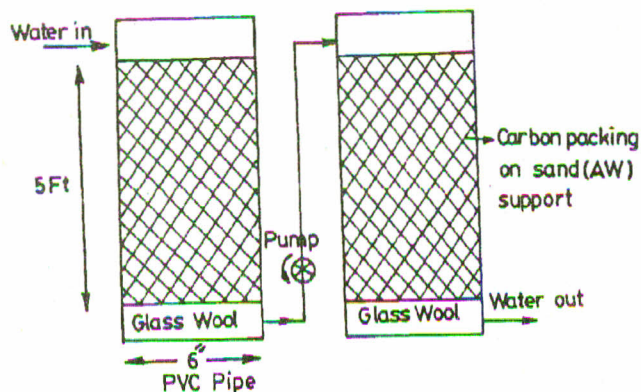


Fig. 3. Two beds in series with configurational details.

achieved under the following operating conditions: space velocity 1.0 L/h; space volume $2.65 \times 10^4 \text{ cm}^3$; carbon amount 2.5 kg per bed; operation mode 2-stage, pump-driven; contact time $2 \times 30 \text{ mins.}$, pre-treatment filtration. All trace metal determinations on amounts adsorbed and in post and pre-filtered waters were made using a Hitachi atomic absorption spectrophotometer (Model 170-10) using standard analytical conditions for the metal analysis.

Results and Discussion

Data on physical characteristics of various activated carbons used in the present study are presented in Table 1, while the trace metal removal data are given in Table 2. Carbon C-4, having greatest specific area, is found to be the most suitable for trace metal removal. The percent removal of various metals achieved with this carbon varied between 41.6-54.6% (Table 2), while in the case of other carbons the removal ranged between 30.5-40.1%, hence their data are not reported. As might be inferred, carbon with maximum particle size and minimum density is found more suitable for the adsorption process, a criterion justifiably based not only on the adsorption ability of the carbon but also on physical

TABLE 1. SOME PHYSICAL CHARACTERISTIC OF CARBONS USED IN THE STUDY.

Carbon code	Toughness (%)	Density (g/ml)	Particle size (mm)	Specific surface (m^2/g)
C-1	91	0.45	0.66	1210
C-2	89	0.49	0.71	1180
C-3	93	0.50	0.62	1130
C-4	95	0.43	1.00	1220
C-5	96	0.48	0.65	970

TABLE 2. PRE AND POST TREATMENT TRACE METAL CONCENTRATIONS* IN NATURAL WATERS.

Water sample	Trace metal	Concentration (mg/L)		Removal %
		Pre-treatment	Post-treatment	
Spring water (pH=7.6)	Fe	0.636	0.264	41.6
	Cr	0.054	0.023	44.1
	Zn	0.364	0.165	54.6
	Cu	0.059	0.027	46.0
	Pb	0.054	0.031	42.6
	Cd	0.022	0.010	54.5
Simli Lake water (pH = 7.2)	Hg	0.004	0.002	50.0
	Fe	0.028	0.015	46.4
	Cr	0.026	0.012	53.8
	Zn	1.953	0.989	49.3
	Cu	0.103	0.050	51.4
	Pb	0.039	0.018	53.8
	Cd	0.030	0.016	46.6
	Hg	0.002	0.001	50.0

*C-4 based, 2-stage, $2 \times 30 \text{ mins}$ contact time

toughness, operation characteristics related to density, particle shape/size and uniformity. In fact, the metal uptake capacity depends on the surface area of the adsorbent available to the adsorbate. As the total surface is basically the internal surface of the walls of the micro-pores, the capacity becomes independent of particle size, and is not increased by decreasing the size of carbon granules, a fact duly supported by the present data.

Out of the 4 modes of operation of filtration beds of various types (*viz.*, down-flow of fixed beds, up-flow of expanded beds, pulse-flow and fluidized flow) the down flow technique is the most convenient one from the view point of application and is preferred in large-scale applications of water treatment since back-washing can be achieved rather directly with such beds [8]. Thus mode of operation was therefore, adopted in the present study. The two fixed beds in series (Fig. 3) provided maximum contact time to the metal ions, and the adsorption equilibrium could be easily established even at surface loading rates between 5-15 m³/hr/m². Space velocity was found to be the most useful parameter influencing trace metal removal. The affinity of various adsorbing species in relation to the available pore size in the carbon surface required that the space velocity should not change with flow volume. During the present investigation it was found that space velocity within the range of 1-5 m³/hr/m³ fulfilled this requirement. The loading rates were found to be ideal between 16 - 32 cm³/min/cm³. The breakthrough curves of (Fig. 2) indicated an optimum throughput corresponding to 60 mins. contact time. The trace metal removal efficiency increased when multiple contact times were utilized.

The arrangement of carbon beds in series was tentatively made to allow for a maximum contact time providing higher degree of treatment. The 2-stage-filtration, though economical in operation costs more because of back-flushing and regeneration of spent carbon. It was found that a 3-stage filtration bed involving 3x60 min. contact time provided enhanced removal of the trace metals to about 75%. Such systems could be used in treatment situations calling for removal or larger amounts of metal contaminants. However, this could be economically constrained since the bed would require a more frequent washing and renewal, especially when large capacity treatments for encountered. An effective solution to this problem was adopted during the present work by introducing filtration of the water sample prior to treatment. This increased the effective number of cyclic runs to about 300, as against 175 without prefiltration. The regeneration of carbon was achieved by heating the acid-washed spent carbon at about 800° for 8 - 12 hrs. At lab-scale the treatment cost was found not to offset the convenience provided by the technique, yet the

methodology ensured a direct and safe procedure for the production of trace metal free water for various applications.

The selection of water samples subjected to the GAC-sand treatment was rather tentative. Only those waters containing trace metal levels in excess to drinking water standards were selected. For example, Fe in drinking waters is tolerable by Health Authorities [15,16] up to 0.30 mg/L. The Fe content of the spring water (Table 2) was 0.636 mg/L, being almost twice as high compared with the allowed limit. After treatment on the GAC-sand bed, its level decreased to 0.264 mg/L, within the safe limit. The same was the situation with Cr initially present at 0.054 mg/L dropping to 0.023 mg/L, within the permissible safe limit of 0.050 mg/L. In post-treated water, zinc was found to be within safe limit of 5.0 mg/L. However, copper and lead exceeded the safe limit of 0.05 mg/L and 0.01 mg/L, respectively. The Simli Lake water had relatively low concentrations of metals compared with the spring water, but exhibited almost comparable percent removal.

Finally, the proposed GAC-sand fixed bed water treatment technique can be usefully employed for removing excessive burden of trace metals in natural waters. It may be extended to large-scale treatment of raw and waste waters of varied origins. Moreover, the carbon loaded beds could be used to solve the colour, odour and turbidity problems associated with most natural waters. Thus, neat potable water could be generated. The small-scale treatment may also find viable application in such industries as food products, paper products, organic/inorganic chemicals, medicinal chemicals, to name a few.

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